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Functional Requirement Specification

162.5 MHz SOLID STATE 7 KW AMPLIFIER, FRS

ED0003673, Rev. -

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Rev.	Date	Description	Originated By	Section No.	Approved By
-	16 SEP 2015	Initial Release – Uploaded into Teamcenter	*Ralph Pasquinelli*	All	*As noted*
-	10 Nov 2016	Updates for Bid Package	*David Peterson*	All	

INTRODUCTION

A superconducting linac is a major part of the Proton Improvement Program – II (PIP-II). It utilizes 162.5 MHz RF power. Advances in solid-state FET device manufacturing have enabled solid-state amplifiers to challenge tube amplifiers at the required power levels.

The accelerator will initially be pulsed at 20 Hz with a minimum pulse length of 6 msec to minimize cryogenic power. With future upgrades the intention is to operate the linac in CW regime to support experiments with high duty factors.

The current PIP-II design requires three levels of RF power in the 162.5 MHz section of the linac. They are 75 kW for the RFQ and 3 kW for the MEBT and first HWR cavity, and 7 kW for the balance of the HWR cavities. This FRS is concerned solely with the 7 kW level.

SCOPE OF WORK

The following is the major task to be completed for the RF power source program:

1. Design and fabrication of a 7 KW CW 162.5 MHz amplifier.
2. Final testing of the amplifier will be performed at Fermilab.

KEY ASSUMPTIONS, INTERFACES, AND CONSTRAINTS

All amplifiers will be "stand alone" systems. The following interface features are required: Forward and reverse power monitors, reverse power trip indicator, DC power supply voltage and current monitor, over temperature trip indicator, and water flow read-back and a locally settable upper/lower water trip indicator. The temperature trip indicator should be from the chill plate for the amplifiers and circulators. The units will be standard 19-inch rack mountable. If the weight of the amplifier and power supplies exceeds 25 kilograms, a sticker indicating the weight should be affixed to the front panel.

REQUIREMENTS

Technical Requirements

162.5 MHz 7 KW CW amplifiers

Vibration and Shock:	Subassemblies must be tested on a shake table for 24 hours to simulate shocks similar to those experienced during shipping.
Remote/local control and read back:	The control interface must include remote and local operation of the amplifier. A touch screen (or equivalent means of self-contained local operation) built into the unit is acceptable. The need for a remote screen, mouse, keyboard, or laptop is NOT acceptable. A remote/local switch shall be located on the front panel of one of the amplifier/power supply chassis. The function of this switch is to allow complete control in local mode (on, off, reset) with read indications both locally and remote. Indicators for local or system faults must be on the front panel or screen. All amplifier parameters should be displayed on the front panel interface and

also via an Ethernet port. For pulsed operation, a sample and hold circuit that averages a number of pulses (ten) should be employed. The sample and hold circuitry will be required for pulsed operation and should be capable of monitoring all critical pulsed parameters. If necessary, the sampled outputs may also be necessary for interlocks and protection. The amplifier must be protected from faults in the pulsed mode. Remote control connections should be on a back panel. Remote read out of RF power transistors bias and currents is required via the Ethernet port. Additional Ethernet monitors of RF power are welcomed.

Details of hardware interface wiring:

1) Preferred signaling for high speed inputs such as RF Gating, Pulse timing trigger, etc. is 5V TTL with 50 ohm terminations. BNC connectors are preferred
2) Preferred signaling for slower interlock, control, and status is +24V DC and up to 20mA.
3) Preferred signaling for analog
4) Signals must be on a multi-pin, locking connector. D-type with retaining screws is preferred.
5) Each Amplifier Status output shall be the Collector-Emitter (or Drain-Source) pair of an optocoupler. This allows for either sourcing or sinking outputs. If pin count is a concern, open collector (drain) outputs with all common emitters (sources) are acceptable. Transistors should be rated for at least 35V and 30mA.
6) Each Amplifier control input shall be the Anode-Cathode pair of the input LED of an optocoupler. This allows for either sourcing or sinking inputs. Current limiting resistors or other devices are permitted. If pin count is a concern, inputs requiring external open-collector signaling are acceptable. Inputs requiring current sourcing are also acceptable.
7) Inputs and outputs shall be protected against static discharge, over-voltage, and over-current conditions.

Center Frequency:	162.5 MHz
Bandwidth:	4 MHz minimum
Power output @ 1dB compression	7 kW CW
Gain:	65 to 68 dB, full power with +0 dBm to +3 dBm drive, lower drive levels to achieve full output power are also acceptable.
Harmonics	-25 dBc

Spurious	<70 dBc plus minus 10 MHz from center frequency
AM to PM deviation	over a 10 dB range to 7 kW, 10 degrees (includes phase shift from temperature variation)
Group Delay	not to exceed 100 nanoseconds
Noise Figure:	20 dB max, measuring of the noise figure should be performed on the predriver as this is the stage that sets the noise figure. This is a standard test for RF amplifiers. The noise figure of a high gain high power amplifier is not straightforward, hence testing of the pre-driver is essential.
Input overdrive protection:	+16 dBm max
Input/output impedance:	50 ohms, input return loss < -15 dB minimum, 50 ohms output, Each amplifier module is to be protected from damage against output open or short circuits. If an internal circulator is used, it should utilize the same chill plate as the amplifier output plates and shall be optimized for 1 dB compression power and 28 +/- 2 °C input water temperature. (see cooling below) Fermilab will supply an external circulator capable of full power protection when installed at Fermilab. Fault indicators for forward and reflected power should be located on the local front panel and reported via the remote connection.
Input connector:	Type N female, rear panel
Output sampling:	Calibrated dual directional coupler internal to the amplifier after the circulator, sampling both forward and reflected power. Both signals should be split with one sample going to the front panel of the RF section, the other sample going to a calibrated log detector and reported both locally and on the remote interface. A sample and hold will be necessary for pulsed operation. Additional monitoring of amplifier modules is acceptable.
Output connector:	1-5/8 inch EIA flange, rear panel of the RF section
Packaging:	19-inch standard rack, maximum depth of 27 inches (68.6 cm). Preferred in two units, RF section and Power supply section. It is acceptable for the RF output connection to exceed the depth requirement.
DC power	All amplifiers must include an integral DC power supply meeting load requirements and providing current limiting of DC power to the RF module. DC connector between power supply and RF section should be adequate for the expected currents and shall have no exposed conductor surfaces. The DC power supplies must be powered with 3 phase circuits. High efficiency (90-95%) power

	supplies recommended. If not water-cooled, provide power level to be dissipated to the HVAC system.
AC power voltage:	480 VAC 60 Hz three phase delta, 4 wire (three phases and ground). Connector shall have no exposed voltage surfaces.
Efficiency goal:	AC plug to RF output >60% goal, 50% minimum at 1 dB compression power
Cooling:	Water-cooled utilizing low conductivity water (LCW) pressurized to a maximum of 125 psi and a minimum differential pressure of 60 psi. To protect the amplifier, the heat load and thermal impedance must be calculated and in compliance with the input water temperature. Cooling water paths should be in parallel for each of the power amplifier modules. The input water temperature will be regulated to 28 C plus minus 2 degrees C. The amplifier must run over a +/- 5 C above 28 degree C (i.e. 23 to 33 degree centigrade) water temperature range without tripping, and it is understood the amplifier may run in a de-rated mode if the nominal temperature range is exceeded. Outside this temperature range, the RF signal input to amplifier unit will be switched OFF. The intention here is to avoid nuisance trips in a large accelerator system. There cannot be any plastic fittings or O-rings used in the water-cooling connections. All water-cooling connections should be of stainless steel, copper or good quality hose pipes inside the unit only. Brazing of water connections is preferred to threaded connections internally. If air-cooling is utilized in either chassis, there should be an indicator of fan function both local and remote. Airflow direction should be intake front panel to exhaust side or back panels. The front panel should have brackets for holding filter media. This filter media must be easy to replace in the field requiring few if any tools. Filters should be of a standard available size, i.e. no custom air filters. All water connections should be tested to 150 psi with no leaks. Up to 15% (of total AC power needed for the RF unit) heat dissipation is acceptable, a higher value will require negotiation due to the added cost of HVAC. Heat load in watts that will be exhausted to the service building will be provided.
Thermal overload:	A +65 deg C shutdown max with front panel indicator is desired, over temperature fault also reported to the remote interface. Monitoring of temperature is on the heat sink. A value lower than this must be negotiated.
Ambient conditions:	+10 to +40 C, 95% humidity non-condensing. A temperature beyond +15 to +35 C will generate a warning, but not trip the amplifier until the higher range (i.e. RFPA will trip for ambient temperature equal to and above 40 C) is exceeded. Note: historically, service buildings at Fermilab can exceed 40 C due to a break down in building cooling. The amplifier must be protected

	for excessive ambient temperature. If the air-cooling load is excessive, it may cause the relay rack where the amplifier is installed to achieve elevated temperatures. Please provide in watts the heat load to ambient so that HVAC can be designed accordingly.
Reliability:	The amplifier shall be run for a full power burn-in period of 100 hours prior to shipment. MTBF shall be greater than 24 hours with greater than 20,000 hours preferred.

Safety Requirements

The following is a list of safety-related requirements for solid-state amplifier development.

1. The amplifier/power supply should be adequately fused/circuit breaker to prevent over current operation. The fuses/circuit breakers should be easily accessible from the front or rear panel and must be for 3-phase AC power.
2. Temperature monitoring and or Klixons should be used to interrupt operation in over temperature conditions reporting to both local and remote interfaces.
3. RF power monitoring should have forward and reverse power trip capability. The trip levels should be settable by the end user. Sample and hold circuit will be necessary for pulsed operation.
4. All water-cooling piping manifolds inside amplifier module must be constructed from copper or stainless steel with brazed connections. The use of high quality hoses with quick disconnects is acceptable if they meet the pressure requirements. Each assembly must be pressure tested and documented to at least 150 psi. The water connections should be on the back panel.
5. Water flow monitoring and interlock protection must be included. Vortex type flow meters with temperature and flow interlock contacts are preferred. Paddle wheel type flow meters should be avoided as they are prone to clogging with the smallest debris in the water. Monitoring of flow must be available both at a front panel indication as well as for remote monitoring.

Quality Assurance Requirements

The most important aspect of maintaining reliable operation of solid-state amplifiers will be the development of written operating procedures for the amplifier, handling and installation instructions, as well as amplifier testing results as performed at point of manufacture.

Test/Commissioning Requirements

The amplifiers should be completely tested before delivery to Fermilab. This will include continuous operation for a period not less than one week at full output power. Note also that the amplifier will be operated in pulsed mode with a 12% duty cycle at 20 Hz. There should be no difference in operating

parameters in this mode other than sample and hold circuitry for data acquisition. Appropriate loads and cooling should be utilized. A full documentation set shall be supplied with the first delivered unit(s). This package will include block diagrams, detailed schematics and interconnection drawings, parts list, assembly and maintenance procedures.